## Title

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# Abundance, Species Richness, and Reproductive Success of Tidal Marsh Birds at China Camp State Park, Marin County, California

Julian K. Wood[1,2], Leonard Liu[1], Nadav Nur[1], Mark Herzog[1,3], and Nils Warnock[1,4]

## ABSTRACT

Extensive habitat loss and degradation have resulted in decreases in populations of tidal marsh breeding birds in the San Francisco Estuary in the past 150 years. We conducted point count surveys and nest monitoring in tidal marsh habitat at China Camp State Park from 1996 through 2007 to assess bird abundance, species richness and reproductive success over time. We found overall species richness at China Camp to be significantly lower than that of other San Pablo Bay tidal marshes, but also to be increasing during the study period. We present relative density indices and confirm breeding for three focal species that are of conservation concern: San Pablo song sparrow (*Melospiza melodia samuelis*), California black rail (*Laterallus jamaicensis coturniculus*), and California clapper rail (*Rallus longirostris obsoletus*). Song sparrows were observed at higher densities at China Camp than at other San Pablo Bay sites. There was no apparent trend in song sparrow density during the study period at China Camp, in contrast with the rest of San Pablo Bay, which displayed a significant decline. We determined song sparrow nest survival probability using the method described by Mayfield (1975) and found that nest survival at China Camp varied markedly among years, from >30% in 1996 to 6% in 2006, with no discernible trend. The main causes of nest failure were predation and tidal flooding. Song sparrow nests were found predominantly in gumplant (*Grindelia stricta*) and pickleweed (*Sarcocornia pacifica*) and less commonly in saltgrass (*Distichlis spicata*). Clapper rails nested exclusively in pickleweed and black rail nests were found mainly in gumplant and less commonly in saltgrass. China Camp's expansive ancient marsh supports endemic and bird species of conservation concern, while serving as a reference site for tidal marsh studies in San Francisco Bay. The long-term monitoring of tidal marsh bird breeding parameters at China Camp has the potential to provide early detection of declining population trends before local populations become imperiled.

## KEY WORDS

song sparrow, California clapper rail, California black rail, density, nest survival, salt marsh

## INTRODUCTION

Tidal salt marsh is critical habitat for the persistence of many bird species (Burger 1985) and supports

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many endemic species or subspecies (Greenberg and Maldonado 2006). While diversity is generally low in salt marsh habitat, many of the species that rely on this habitat type are highly specialized (Chapman 1977). North America supports the highest number of terrestrial vertebrate species with subspecies endemic to tidal salt marsh (Greenberg and Maldonado 2006), and birds compose the majority of these endemic subspecies. On the west coast of the United States, the majority of these subspecies occur in the San Francisco Bay.

The San Francisco Bay and Delta contain the largest area of tidal marsh (162 km$^2$) along the Pacific Coast (Nichols and others 1986), and support populations of endemic subspecies such as the federally endangered California clapper rail (see Table 1 for scientific names), and the State of California threatened California black rail. Other endemic subspecies include the following State of California Bird Species of Special Concern: the San Francisco common yellowthroat, and three subspecies of song sparrow: Suisun song sparrow (*Melospiza melodia maxillaris*),

**Table 1** Bird species detected at China Camp, breeding status and density index (mean no. of individuals detected per ha). Breeding status: CO = confirmed (nest found, nesting activity observed), PR = probable (pair or permanent territory throughout breeding season in suitable nesting habitat), PO = possible (detected during breeding season in suitable nesting habitat). Data from March through May 1996 through 2007 point count surveys and incidental sightings (excludes flyovers and species detected only in the bay).

| Common name | Scientific name | Breeding status | Relative density |
|---|---|---|---|
| Western grebe | *Aechmophorus occidentalis* | | 0.01 |
| Clark's grebe | *Aechmophorus clarkii* | | 0.05 |
| Great blue heron | *Ardea herodias* | | ---a |
| Great egret | *Ardea alba* | | ---a |
| Snowy egret | *Egretta thula* | | 0.9 |
| Turkey vulture | *Cathartes aura* | | ---a |
| Canada goose | *Branta canadensis* | | ---a |
| Gadwall | *Anas strepera* | PR | ---a |
| American wigeon | *Anas americana* | | ---a |
| Mallard | *Anas platyrhynchos* | CO | 0.04 |
| Lesser scaup | *Aythya affinis* | | 0.01 |
| Ruddy duck | *Oxyura jamaicensis* | | ---a |
| Osprey | *Pandion haliaetus* | | ---a |
| White-tailed kite | *Elanus leucurus* | PO | ---a |
| Northern harrier | *Circus cyaneus* | PR | ---a |
| Red-shouldered hawk | *Buteo lineatus* | | ---a |
| Red-tailed hawk | *Buteo jamaicensis* | PR | ---a |
| California black rail | *Laterallus jamaicensis coturniculus* | CO | 0.26 |
| California clapper rail | *Rallus longirostris obsoletus* | CO | ---a |
| Virginia rail | *Rallus limicola* | | ---a |
| Killdeer | *Charadrius vociferus* | | 0.01 |
| Black-necked stilt | *Himantopus mexicanus* | | 0.08 |
| Greater yellowlegs | *Tringa melanoleuca* | | ---a |
| Willet | *Catoptrophorus semipalmatus* | | ---a |

a Density index <0.01 birds ha$^{-1}$

**Table 1** (Continued) Bird species detected at China Camp, breeding status and density index (mean no. of individuals detected per ha). Breeding status: CO = confirmed (nest found, nesting activity observed), PR = probable (pair or permanent territory throughout breeding season in suitable nesting habitat), PO = possible (detected during breeding season in suitable nesting habitat). Data from March through May 1996 through 2007 point count surveys and incidental sightings (excludes flyovers and species only detected in the bay).

| Common name | Scientific name | Breeding status | Relative density |
|---|---|---|---|
| Least sandpiper | *Calidris minutilla* | | 0.01 |
| Wilson's snipe | *Gallinago delicata* | | 0.05 |
| Western gull | *Larus occidentalis* | | ---a |
| Mourning dove | *Zenaida macroura* | CO | ---a |
| Anna's hummingbird | *Calypte anna* | PO | ---a |
| Allen's hummingbird | *Selasphorus sasin* | PO | ---a |
| Acorn woodpecker | *Melanerpes formicivorus* | | ---a |
| Northern flicker | *Colaptes auratus* | | ---a |
| Pacific-slope flycatcher | *Empidonax difficilis* | | 0.01 |
| Say's phoebe | *Sayornis saya* | | ---a |
| Western scrub-jay | *Aphelocoma californica* | | ---a |
| American crow | *Corvus brachyrhynchos* | | ---a |
| Common raven | *Corvus corax* | | 0.05 |
| Tree swallow | *Tachycineta bicolor* | | 0.07 |
| Violet-green swallow | *Tachycineta thalassina* | | 0.02 |
| Cliff swallow | *Petrochelidon pyrrhonota* | | ---a |
| Barn swallow | *Hirundo rustica* | | 0.02 |
| White-breasted nuthatch | *Sitta carolinensis* | | ---a |
| Marsh wren | *Cistothorus palustris* | CO | 0.17 |
| Western bluebird | *Sialia mexicana* | | ---a |
| American robin | *Turdus migratorius* | | ---a |
| European starling | *Sturnus vulgaris* | | ---a |
| San Francisco common yellowthroat | *Geothlypis trichas sinuosa* | PO | ---a |
| Spotted towhee | *Pipilo maculatus* | | ---a |
| California towhee | *Pipilo crissalis* | | 0.01 |
| San Pablo song sparrow | *Melospiza melodia samuelis* | CO | 7.57 |
| White-crowned sparrow | *Zonotrichia leucophrys* | | ---a |
| Red-winged blackbird | *Agelaius phoeniceus* | PO | 0.26 |
| Western meadowlark | *Sturnella neglecta* | | ---a |
| Brown-headed cowbird | *Molothrus ater* | CO | ---a |
| House finch | *Carpodacus mexicanus* | | 0.09 |
| American goldfinch | *Carduelis tristis* | CO | 0.06 |

a Density index <0.01 birds $ha^{-1}$

Alameda song sparrow (*M. m. pusillula*), and San Pablo song sparrow (*M. m. samuelis*) (Shuford and Gardali 2008).

China Camp, located on the eastern shore of Marin County in San Pablo Bay, is one of the largest ancient marshes in San Pablo Bay, and was formed 2,000 to 6,000 years ago (Atwater 1979). The marsh plain is dominated by pickleweed (*Sarcocornia pacifica*) and characterized by complex dendritic networks of channels lined with gumplant (*Grindelia stricta*). The younger, outward edge of the marsh (also referred to as "centennial marsh") formed over the last 150 years and is dominated by bulrush (*Schoenoplectus maritimus*) with a dynamic fringe of Pacific cordgrass (Atwater and others 1979; Jaffe and others 2007; Baye 2011). China Camp marsh is 99 ha (based on USGS aerial photos) and has been used as a reference site for evaluating the condition of restored, degraded and managed marshes (Williams and Orr 2002; Baye 2011). In addition, the natural interface between tidal salt marsh and protected uplands that exists at China Camp is now rare elsewhere in San Francisco Bay. China Camp's extensive, undisturbed and ancient marsh plain and its upland transitional zone all contribute to making this area an important reference site for researchers.

Extensive bird research has been conducted at China Camp, including studies of species abundance and distribution (Nur and others 1997; Takekawa and others 2006; SFEIT 2011), trophic adaptations (Grenier 2004), and genetic structure (Chan and Arcese 2002). While many of the above studies focused on the song sparrow, earlier studies were conducted on clapper rail (Gill 1979) and black rail (Evens and others 1991; Evens and Nur 2002). PRBO Conservation Science (PRBO) initiated a long-term tidal marsh monitoring program in 1996, and has used China Camp as a key reference site in describing bird abundance, distribution, and demographics in relation to local and landscape-level characteristics (Spautz and Nur 2002; Greenberg and others 2006; Spautz and others 2006; Nur and others 2012).

The objectives of this study were to summarize bird species richness, relative abundance, and demographic parameters at China Camp from unpublished reports and monitoring data collected from 1996 to 2007. Although we provide species richness and relative abundance data on all species, we provide analysis of abundance and summarize nest substrate use for the three most common bird species at China Camp—black rail, clapper rail, and song sparrow—found throughout San Francisco Bay tidal marshes. For the song sparrow, we examined trends in abundance and nesting success, and compared these results to those at other long-term monitoring sites in San Pablo Bay.

## METHODS

### Study Area

Bird monitoring data were collected in tidal salt marsh habitat within China Camp State Park, Marin County, CA (Figure 1). Point count stations, nest plots, and territory-mapping plots were placed throughout the site non-randomly in an effort to sample the range of habitat conditions (e.g., channels, pickleweed plain, and bulrush-dominated areas) at China Camp. Point count stations were located at least 50 m from the upland and bay edges. Sub-tidal mudflats and upland areas within and adjacent to China Camp were not surveyed as part of this study.

### General Point Count Survey

Between 1996 and 2007, point count surveys were conducted each year at 7 to 23 marshes in San Pablo Bay during spring (late March through May). Survey points (or stations) were placed 150 to 200 m apart, with 10 points surveyed at China Camp in most years, and 5 to 13 points per site at other San Pablo Bay sites, depending on marsh size. In nearly all cases, two surveys were conducted at each station, and successive rounds were conducted at least 3 weeks apart. At each station, a trained field biologist recorded all birds detected by sight and sound for 5 minutes. For detections within 100 m from the observer, distance was estimated within 10-m bands (Reynolds and others 1980; Ralph and others 1995; Nur and others 1999). Based on prior analysis of detection rates at various distances (Nur and others 1997), we restricted the data used in the results to

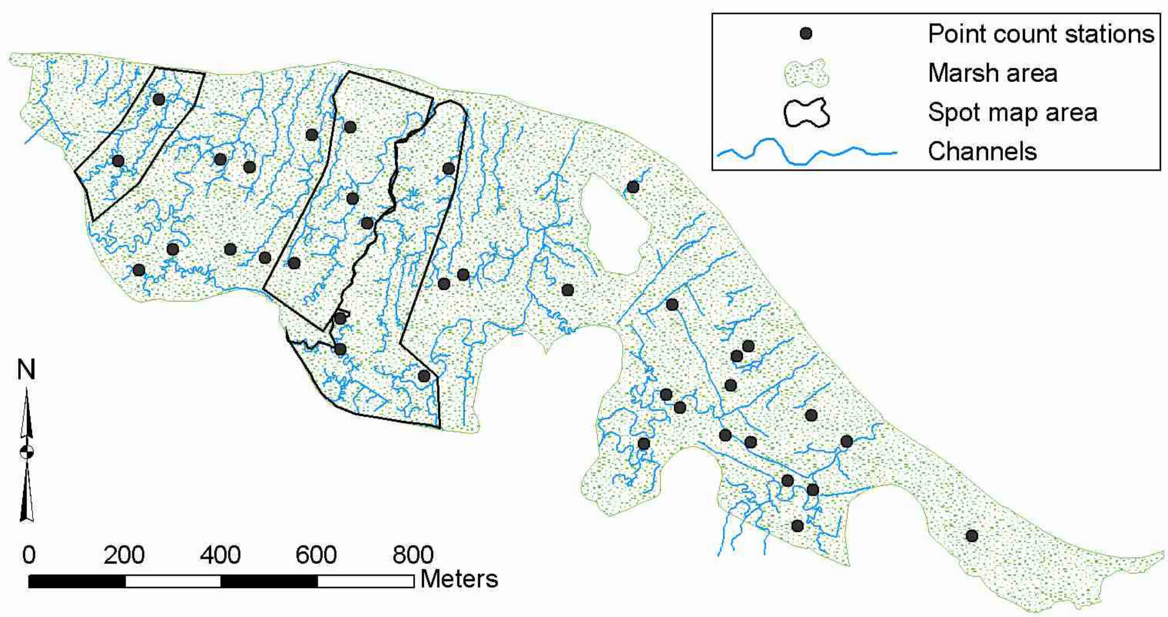


**Figure 1** Map of the China Camp study site showing spot map areas, nest monitoring plots, and all PRBO point count stations conducted during 1996 through 2007. In any given year, only a subset of points was sampled.

detections within 50 m of the observer. Within this area, we did not assume 100% detectability. For purposes of analysis, however, we did assume that there was negligible variation in detectability across sites and years based on previous analysis (Nur and others 1997). Thus, the results obtained are not true density estimates, but instead an index of relative density, as described by Ralph and others (1995) and Nur and others (1999). Relative density was calculated for each 5-minute point count survey and averaged over the two visits, and, for Table 1, were averaged across years. Final average estimates were then divided by the proportion of tidal marsh within the 50-m radius. (See below for the statistical analysis of the point count data.) We defined species richness at the point level as the total number of unique species detected across both surveys within each year. We calculated marsh areas using information on marsh delineation provided by the State Coastal Conservancy's Invasive Spartina Project, the San Francisco Estuary Institute's Bay Area EcoAtlas Version 1.50b4, and USGS aerial photographs.

## Clapper Rail Point Count Survey

From 2005 through 2008, clapper rail surveys were conducted three times each year between January and March. Passive 10-minute surveys were conducted at seven points, at least 200 m apart, during a 2-hour period surrounding sunrise and/or sunset. All clapper rail vocalizations were recorded with the time, direction and distance from the point following Liu and others (2009). The program DISTANCE (Buckland and others 2001) was used to estimate clapper rail densities. Program DISTANCE estimates detection probability, allowing more accurate estimates of actual density, and thus overcoming the problem of detection probability of a bird decreasing with increasing distance from an observer (Thomas and others 2002). Data from all visits to listening stations within a marsh were used to estimate detection probability for each site in each year.

## Territory Mapping

From 2001 through 2005, the breeding territories of black rails and song sparrows were mapped within three spot map areas (Figure 1), totaling 15.3 ha. Clapper rail territory was not mapped because they vocalize infrequently and are seldom seen exhibiting territorial behavior. The territory mapping plots were ideally visited weekly from March through July, although some portions of the spot map area were visited as few as four times during the breeding season: twice during the first half of the season to produce mid-season maps (before May 1) and at least twice during the late season, between May 1 and June 30. Bird detections and territorial behavior (including black rail "kiki-doo" calls) from each visit were compiled onto maps, following Verner (1985), and polygons were drawn around detection clusters, which represented territories. Territory density was calculated based on the number of territories within the spot map area.

### Nest Monitoring

From 1996 through 2007, trained observers following standard protocol searched and monitored nests annually at China Camp, as described in Martin and Geupel (1993) and Nur and others (1997). For all species, we recorded the nest substrate: the plant species upon which the nest was constructed. Nests were located during all stages (construction, egg-laying, incubation, and nestling periods). For all species except clapper rail, nests were visited every 2 to 4 days to record nest contents; clapper rail nests were not visited repeatedly because of permitting restrictions that limited disturbance of breeding pairs. The ultimate outcome of each nest (fledge or fail) was determined based on nest condition and parental behavior as described by Martin and Geupel (1993). Nests were visited after extreme flood events and checked for signs of flooding (e.g., high water and silt marks on nest and vegetation, eggs on the ground, or dead intact nestlings). For the song sparrow, we calculated daily nest survival rates using the method described by Mayfield (1975) and then estimated overall nest survival as the product of the daily nest survival rates over the 23-day nesting period (Johnson 1979; Nur and others 1999). To compare with other studies, we also calculated apparent nest success as the fraction of detected nests that successfully fledged at least one nestling. Apparent nest success, however, is a biased estimator of nest survival, unlike the Mayfield method (Johnson 1979; Nur and others 1999).

## ANALYTICAL METHODS

We present analyses of species richness, including analyses of trends over time (1996 to 2007) using point count data for China Camp and for all other sites in San Pablo Bay (pooled, excluding China Camp). For these analyses, we fit linear models, and confirmed that assumptions of linear models were met (Nur and others 1999). We present analyses of relative density of song sparrows with respect to year (1996 to 2007) for China Camp, and pooled for all other San Pablo Bay marsh sites. Change in density over time was investigated non-parametrically using the LOESS procedure (Cleveland 1979) implemented in STATA 10.0 (StataCorp 2007). In addition, we analyzed change in density for linear, second-order (i.e., quadratic), and third-order functions (Nur and others 1999). In these analyses, we used mean values (for China Camp or San Pablo Bay sites) for each year, weighted by the inverse of the standard error of the mean (to account for heteroskedasticity among mean values). For all parametric analyses we natural-log-transformed density (henceforth referred to as "log-transformed"). Any resulting linear trends in log-density imply a constant percent change in density over time (Nur and others 1999). We used a similar approach to analyze overall nest survival for song sparrows at China Camp, as well as at other San Pablo Bay sites, over the study period from 1996 through 2007.

## RESULTS

Song sparrows were the most common species breeding at China Camp, with fewer nests found for black rail and clapper rail. We confirmed breeding for an additional five species that bred infrequently or in very low numbers (marsh wren, mallard, American goldfinch, mourning dove, and brown-headed cowbird, a brood parasite associated with upland and pasture habitats; see Table 1).

## Bird Species Richness

We detected 56 bird species during general point count surveys at China Camp (see Table 1). Bird species richness per point at China Camp ranged from 1.5 in 1997 and 2000 to 4.1 in 2007 (Figure 2). In most years China Camp appeared slightly lower than the average values for San Pablo Bay sites. Over the 12 years, species richness per point at China Camp was significantly lower (mean = 2.44, S.E. = 0.272) than what was observed at other San Pablo Bay sites (mean = 3.26, S.E. = 0.189; difference in means: $n = 24$, $t = -2.47$, $P = 0.022$). In addition, in China Camp and elsewhere in San Pablo Bay, species richness increased over time. The estimated slope for China Camp was +0.149 species $yr^{-1}$ (S.E. = 0.080), while for all other San Pablo Bay sites it was +0.100 (S.E. = 0.048); however, the difference was not significant ($P > 0.5$). Because of lack of significant difference between the China Camp slope and the slope for other San Pablo Bay sites, we fit a model with separate intercepts but with the same (i.e., common) slope, which was 0.124 (S.E. = 0.041) and which was significantly different from zero ($n = 24$, $t = +3.04$, $P = 0.006$).

## Relative Density and Territory Density

For the 56 bird species detected, mean relative density indices ranged from <0.01 birds $ha^{-1}$ to 7.57 (see Table 1). Clapper rail relative density using clapper rail point count survey data from 2005 through 2008 averaged 0.44 birds $ha^{-1}$, and ranged from 0.275 birds $ha^{-1}$ in 2005 to 0.616 birds $ha^{-1}$ in 2007.

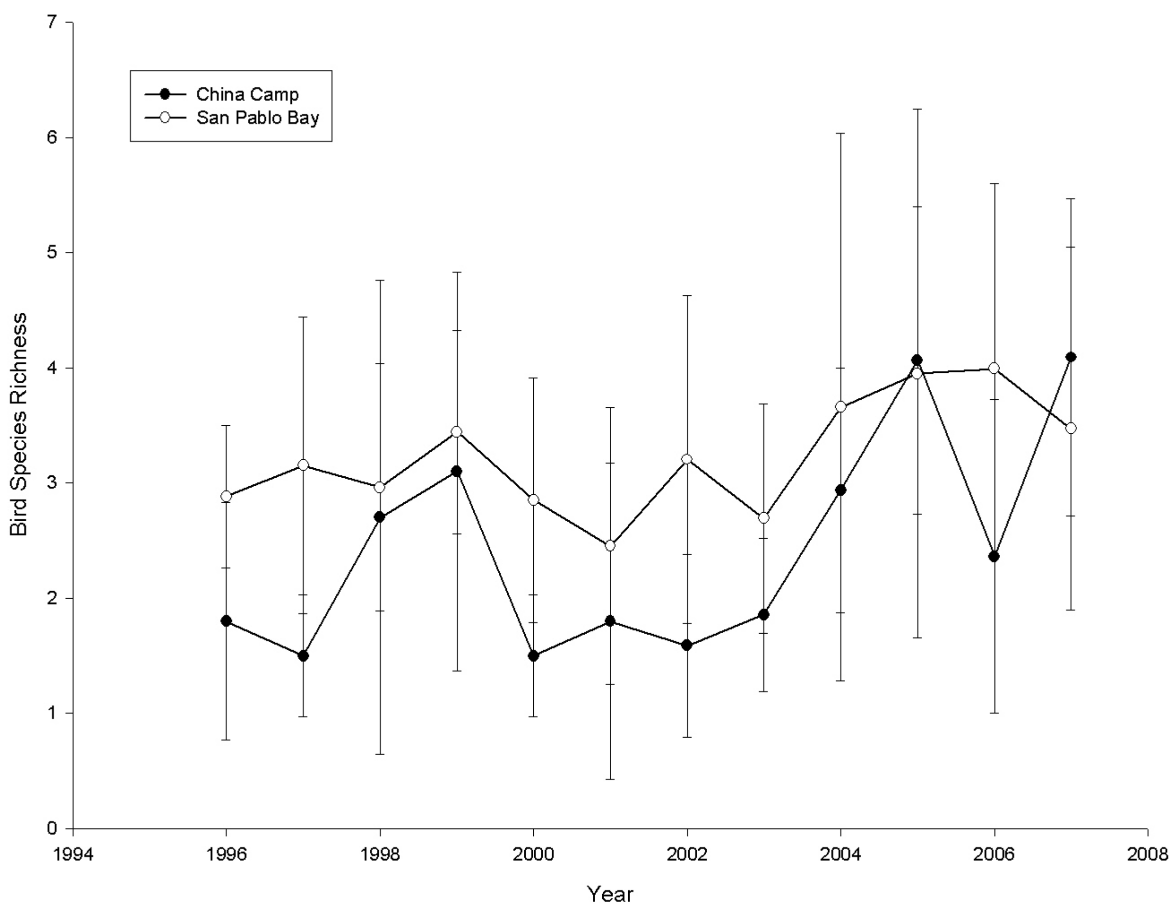


**Figure 2** Mean marsh bird species richness per point at China Camp and San Pablo Bay using point count data (1996 through 2007). Error bars represent one standard error.

Density based on territory mapping data from black rails averaged 0.86 birds $ha^{-1}$ and ranged from 0.66 in 2003 to 1.40 birds $ha^{-1}$ in 2001 and 2004. Mean song sparrow density derived from territory mapping data was 12.94 birds $ha^{-1}$ (S.E. = 0.33, $n$ = 6 yrs), varying from 11.84 to 13.98 birds $ha^{-1}$ in individual years.

Relative density derived from point count data was analyzed in more detail for song sparrow because of the high abundance documented at China Camp, and to compare to other San Pablo Bay sites where territory mapping data was lacking. Relative density of this species ranged from 4.69 birds $ha^{-1}$ (S.E. ± 2.28) to 10.74 (S.E. ± 3.15) at China Camp across the 11 years, and was slightly higher than the average of all San Pablo sites that ranged from 4.61 birds $ha^{-1}$ (S.E. ± 0.28) to 7.20 (S.E. ± 0.36). The mean density index (back-transformed) among years was 31% higher at China Camp than at the other San Pablo Bay sites. The log-transformed mean density index across years for China Camp was 2.00 (S.E. ± 0.064); the log-transformed mean density index across years for all San Pablo sites other than China Camp was 1.73 (S.E. ± 0.035; difference in means: $F(1, 22) = 13.70$; $P = 0.001$; results of weighted regression of log-transformed values). The linear trend for year at China Camp (on log-transformed values) displayed a weak trend (beta = +0.0019, S.E. = 0.0201, $P > 0.9$). At China Camp, the quadratic coefficient in a second-order model fit to year was not significant ($P = 0.069$), and the same was true for the cubic coefficient in a third-order model ($P > 0.4$; Figure 3). In contrast, a significant linear decline in the density index was observed for the rest of San Pablo Bay sites ($P = 0.015$, Figure 4). The estimated constant decline was 2.4% per year (S.E. = 0.091; 95% CI: –0.6% to –4.2%). Neither a quadratic coefficient in a quadratic model nor a cubic coefficient in a cubic model were significant for this set of marshes when analyzing trends over time ($P > 0.15$ or greater). Year-to-year change at China Camp was not correlated with year-to-year change in song sparrow relative density at other sites.

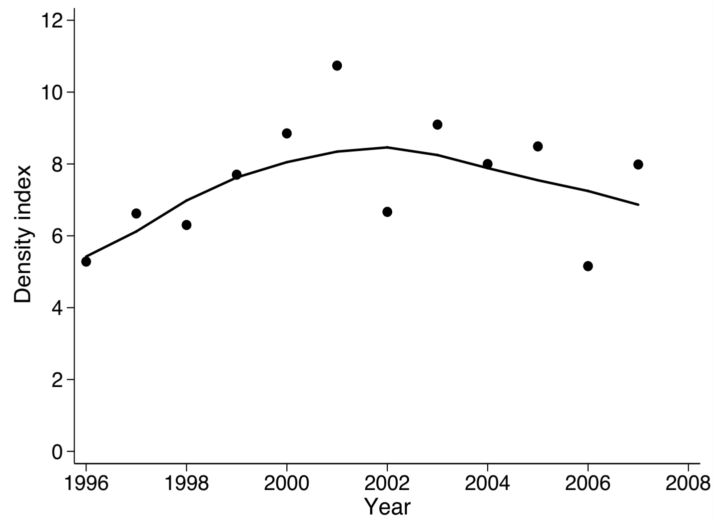


**Figure 3** Mean song sparrow relative density (number of individuals detected per hectare) at China Camp based on point count data from 1996 through 2007. Shown is LOESS smoothed data (see text). No significant linear, quadratic, or cubic trend was detected.

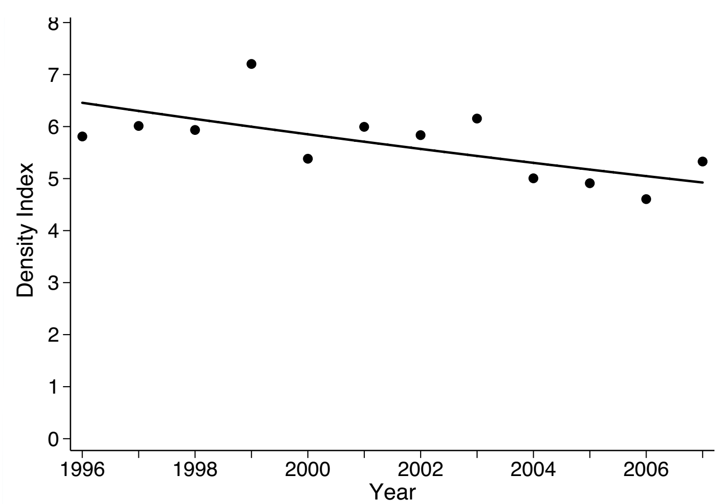


**Figure 4** Mean song sparrow relative density (number of individuals detected per hectare) at all San Pablo Bay sites, based on point count data from 1996 through 2007. The linear decline of 2.4% per year (on *ln*-transformed values) was significant ($P = 0.015$; see text).

## Demography

The average song sparrow nest survival probability, over the entire nesting period, from 1996 through 2007, was very similar between China Camp (16.3%) and the rest of San Pablo Bay (16.0%). Apparent nest success was 24% at China Camp and 27% at other San Pablo Bay sites. Nest survival at all sites was characterized by high annual variation. At China Camp, song sparrow total nest survival varied from 6% in 2006 to 32% in 1996 (Figure 5). No significant trends (linear or non-linear) were found at China Camp. The estimated decline in nest survival per year was 0.27% per year (S.E. = 0.64%; $P > 0.6$). Quadratic and cubic coefficients were not significant ($P > 0.6$). The estimated decline in nest survival for the rest of San Pablo Bay was similar to that of China Camp: 0.55% decline per year (S.E. = 0.53%, $P > 0.3$). Year-to-year changes in nest survival at China Camp were not correlated with year-to-year changes in nest survival at other San Pablo sites.

For song sparrows, the most common nest fate at our sites was predation (Figure 6). Nest fates were similar between China Camp and the rest of San Pablo Bay sites, with the exception of the percent of flooded nests (by spring and storm tides), which was twice as high at China Camp (16%) than at other San Pablo Bay sites (8%).

Of the 16 black rail nests monitored at China Camp from 1999 through 2007, six were confirmed successful (fledged at least one young), six were preyed upon by unknown predators, two were abandoned, and the fate of two nests was unknown.

## Nesting Habitat Use

Song sparrows used three species of plants on which to build their nests at China Camp (Figure 7). At other sites in San Pablo Bay, song sparrows used a greater variety of nesting substrates, and more nests were found in pickleweed and fewer nests were found in gumplant than those at China Camp (Figure 7).

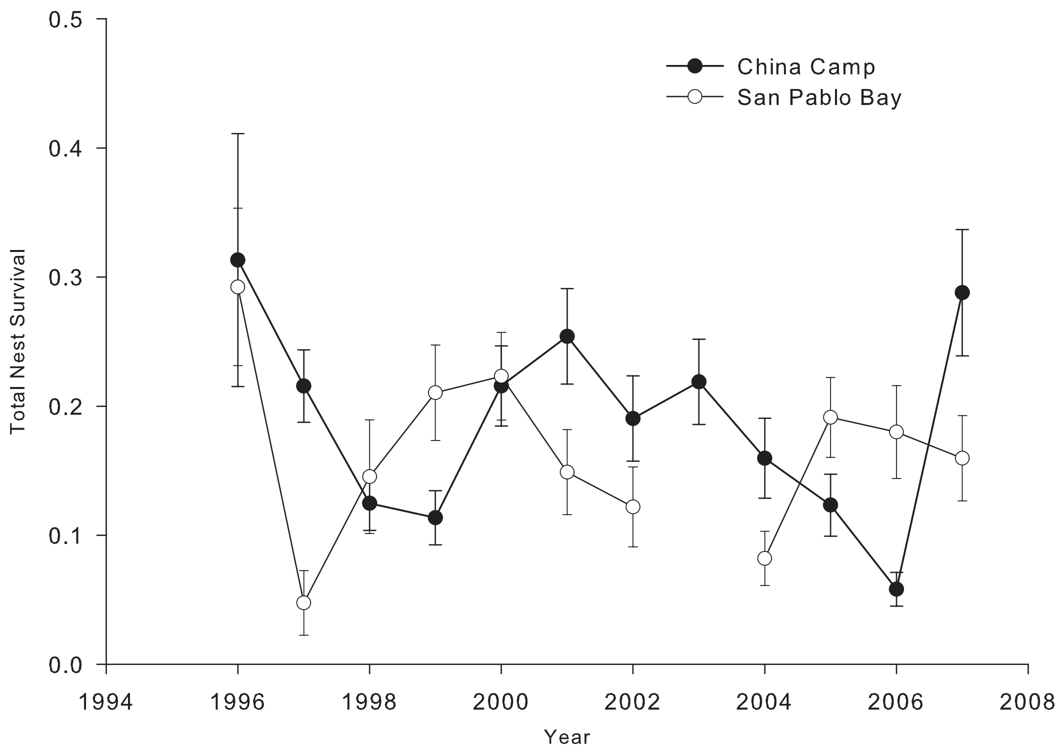


**Figure 5** Song sparrow nest survival (total survival) at China Camp and at all other San Pablo Bay sites, 1996 through 2007. No nest monitoring was conducted at other San Pablo Bay sites in 2003. Error bars represent one standard error. No significant trend in nest survival was found.

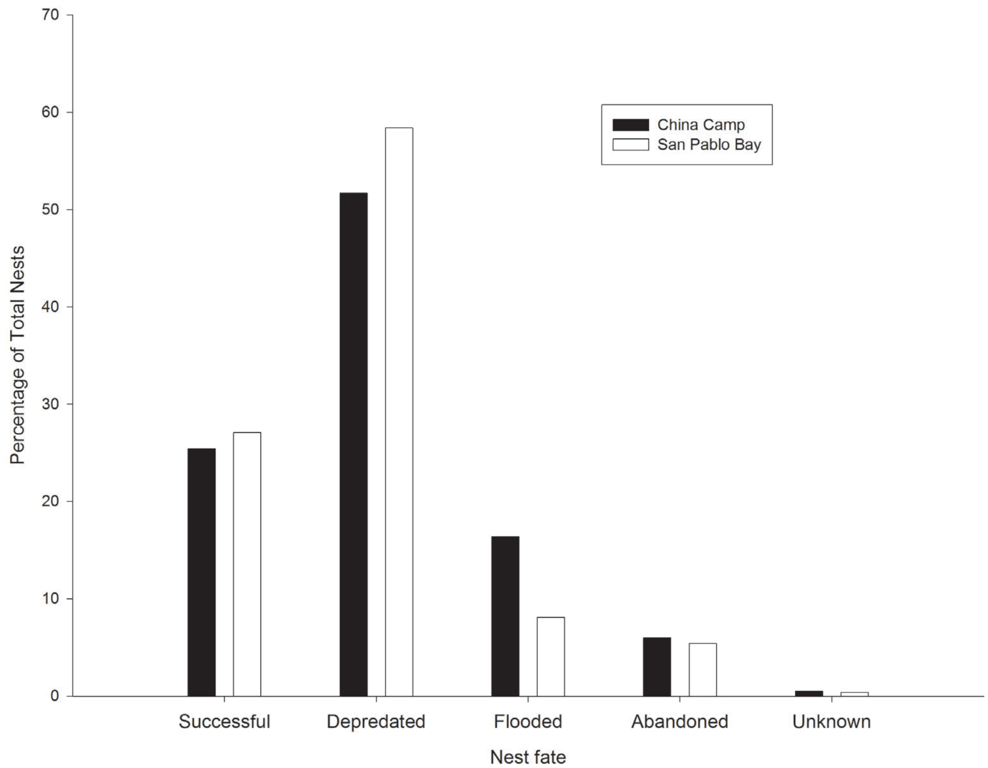


**Figure 6** Song sparrow nest fate at China Camp (*n* = 1,537) and all other San Pablo Bay sites (*n* = 1,088), 1996 through 2007

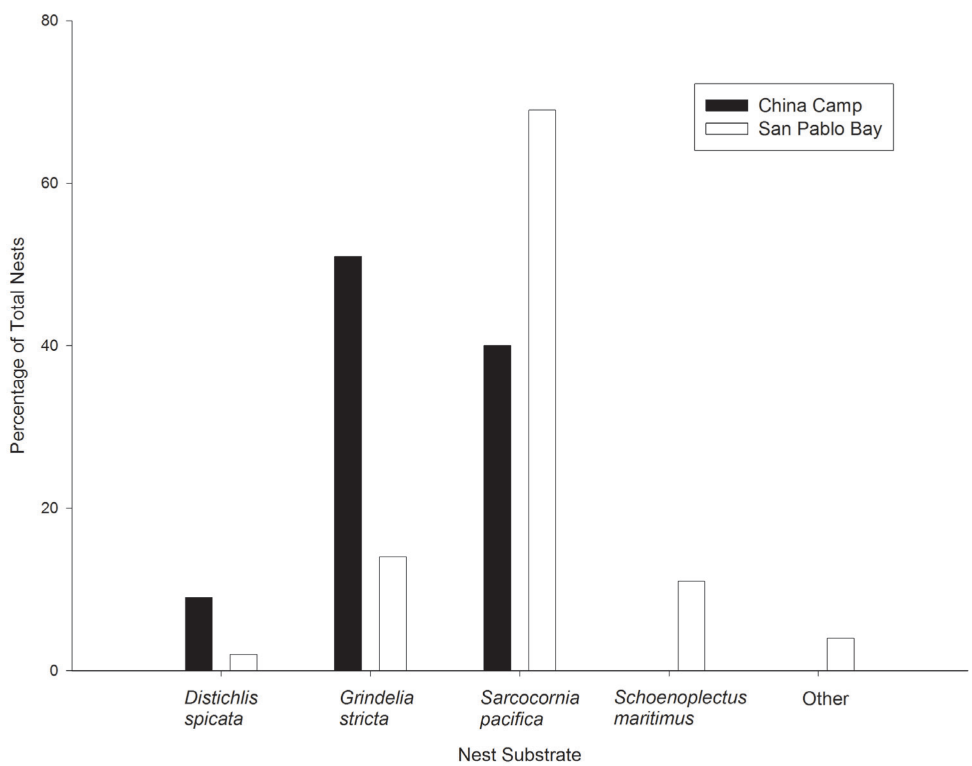


**Figure 7** Nest substrate for song sparrow at China Camp (*n* = 1,537) and other San Pablo Bay sites (*n* = 1,088), 1996 through 2007

Black rail nests at China Camp were found in two plant species (ten nests in gumplant and two nests in saltgrass [*Distichlis spicata*]). For four nests, the plant substrate was not recorded. All 25 clapper rail nests found at China Camp and all other San Pablo Bay sites used pickleweed, though other plant species may have provided additional cover.

## DISCUSSION

### Bird Species Richness

Bird species richness at China Camp was lower compared to northeastern Atlantic coast salt marshes (Hanson and Shriver 2006), which ranged from 3.9 to 8.4 per survey point. China Camp bird species richness was significantly lower than that of other sites in San Pablo Bay. The higher species richness observed at other San Pablo sites may result from greater habitat complexity at those sites. Other San Pablo Bay sites included areas of taller vegetation that is associated with brackish conditions (cattail, *Typha* spp.) and low marsh characterized by early-successional bulrush, which is favored by marsh wrens and common yellowthroats. At China Camp, bulrush was most common on the outward edge of the marsh where marsh wren territories were clustered. Many San Pablo Bay sites also contained salt pans and other open areas that attracted shorebirds and other waterbirds, adding to bird species richness. While overall bird species richness per survey point was slightly lower at China Camp, this site epitomizes a healthy ancient tidal salt marsh, and supported all species that have evolved to specialize in this harsh environment. In fact, many of the other San Pablo Bay marsh fragments lacked black rails and clapper rails (Evens and Nur 2002; Spautz and others 2006).

### Relative Density and Territory Density

Song sparrows were the most abundant species at China Camp, and had higher relative densities than at most other San Pablo Bay sites. Bird-habitat analyses have shown that song sparrows are positively correlated with gumplant, an abundant shrub that lines channels at China Camp, and negatively correlated with rushes, ponds, and pans (Spautz and others 2006) that are lacking at China Camp. In addition, marsh size is an important predictor of song sparrow abundance in San Francisco Bay, with larger marshes, such as China Camp, supporting higher densities (Spautz and others 2006). Hanson and Shriver (2006) also determined that larger marshes had higher densities of salt marsh-obligate sparrows. Johnston (1956a) reported 6 to 8 birds $ha^{-1}$ based on territory mapping along channels at a marsh in San Pablo Bay near Richmond. However, based on territory mapping results, actual densities at China Camp were substantially higher.

### Nest Survival

Apparent nest success of *Ammodramus* sparrows (seaside sparrow *A. maritimus* and saltmarsh sharp-tailed sparrow *A. caudacutus*) from four eastern U.S. salt marshes averaged 41.5% (Reinert 2006), and was higher than both China Camp and San Pablo Bay (24% and 27%, respectively). Predation was the primary nest fate (52%) at China Camp, followed by flooding (16%). A summary by Greenberg and others (2006) found that 47% of song sparrow nests in San Francisco Bay failed because of predation, and 13% because of flooding, compared to 32% from predation and 24% from flooding in East Coast marshes where the dominant nesting substrate is smooth cordgrass (*Spartina alterniflora*). Little is known about nest predators in San Francisco Bay, and more study is needed to elucidate the effect of specific predators on tidal marsh birds. Potential nest predators found in San Francisco Bay include the gopher snake (*Pituophis catenifer*), northern harrier, short-eared owl (*Asio flammeus*), brown-headed cowbird, corvids, river otter (*Lontra canadensis*), and raccoon (*Procyon lotor*). Other potential nest predators include the vagrant shrew (*Sorex vagrans*), California ground squirrel (*Otospermophilus beecheyi*), California vole (*Microtus californicus*), house mouse (*Mus musculus*), and Norway rat (*Rattus norvegicus*) (Johnston 1956b; Josselyn 1983; Albertson 1995). In addition, the marsh wren may be responsible for the destruction of song sparrow nests at China Camp where territories of the two species are in proximity (Picman 1977; Nordby and others 2009).

### Nesting Habitat Use

In San Pablo Bay, song sparrow nests have been found in pickleweed, saltgrass, Pacific cordgrass, and gumplant (Johnston 1956a). Spautz and others (2006) have shown that song sparrow density is positively correlated with the amount of gumplant within the survey area. In our study, song sparrow territories were mostly located along gumplant-lined channels that Johnston (1956b) identified as an important marsh feature for foraging. However, Grenier (2004) found that song sparrows at China Camp also foraged in pickleweed-dominated areas that were outside their defended territories. In addition, habitat use may vary with marsh age within China Camp marsh. Additional data from different age classes (e.g., centennial and ancient marsh) would be required to explore habitat use and marsh age within China Camp. The outer fringe of centennial marsh at China Camp is lower in elevation, has less sinuous channels relative to the ancient marsh, and is dominated by bulrush (Baye 2011). Birds nesting in the centennial marsh may be selecting different types of vegetation for nesting.

In the Northeastern U.S., Ammodramus sparrows nested primarily in smooth cordgrass (*Spartina* spp.) that are taller than gumplant and may allow sparrows to nest above the height of higher tides and still provide concealment from above (Greenlaw 1983; Marshall and Reinert 1990; Gjerdrum and others 2005). Invasion of the non-native hybrid *Spartina* at China Camp marsh, would likely alter song sparrow nest substrate selection, resulting in reduced nest success as well as increased competition and predation from marsh wrens that may favor the taller invasive plants (Nordby and others 2004).

All 25 clapper rail nests at China Camp were found in pickleweed, despite the presence of gumplant along channels. Observations by DeGroot (1927) indicate that clapper rails may have nested commonly in gumplant but transitioned to pickleweed in the early 1900s, as predation and hunting pressures increased. At other sites in San Francisco Bay, clapper rail nests have been found in gumplant, bulrush, and Pacific cordgrass, as well as in pickleweed (Collins and others 1994; Garcia 1995). Massey and others (1984) reported tall, dense Pacific cordgrass was the preferred nesting substrate for light-footed clapper rails (*Rallus longirostris levipes*) in Southern California marshes, but that rails nested in pickleweed where Pacific cordgrass was sparse or insufficiently tall or dense. At China Camp, Pacific cordgrass was mostly found along the outward edge of the marsh and sparsely along channels and was likely not sufficiently tall or dense to support nesting.

## CONCLUSIONS

China Camp, with its expansive ancient marsh buffered by natural uplands and younger outward marsh, has provided researchers the opportunity to study the natural history and ecology of salt-marsh dependent birds in a setting that approximates historical conditions. China Camp supports a stable population of song sparrows and also harbors populations of California black rails, listed as state of California Threatened, and California clapper rails, a federal- and state-listed endangered species. These populations face many threats, including sea-level rise, invasive species (e.g., smooth cordgrass *Spartina alterniflora*/hybrids), pollution, and non-native predators.

Myriad threats to China Camp's bird community warrants continued monitoring to provide early detection of decreasing trends in abundance and estimates of nest success before populations become imperiled. Nest survival for tidal marsh birds has been identified as an important indicator of estuarine condition for the San Francisco Estuary (SFEIT 2011). Nest survival values below about 23% are too low to sustain San Pablo Bay song sparrow populations (Nur and others 2012). Thus, it is not only changes in nest survival that are important, but also the absolute values of this parameter, which can be determined only through nest monitoring.

Furthermore, long-term viability of tidal marsh populations also requires information on survival of adults and juveniles. Early detection of decreasing trends in abundance, or observations of low nest success will allow time to identify threats and design conservation actions (e.g., restoration, improved management, predator control) to reverse downward trends. Research and monitoring should encompass multiple sites that represent the range of sizes, ages, configurations, and management regimes of marshes throughout the San Francisco Bay. In this way, we can better understand the role China Camp marsh plays within the broader context of the San Francisco Bay as a whole.

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